# Adaptive System for Collaborative Online Laboratories

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***Abstract*—In the last decade, researchers in the Online Engineering field have attempted to provide hands-on, web-based approaches for Distance Learning. The primary goal of this research is to produce online laboratories that serve as the educational substitute for *in situ* laboratories. A limitation of existing online laboratories, however, is that they generally only allow a single user to be connected at a time. Since group learning activities, such as peer assistance, peer emulation, and collaborative experimental setup, are core dimensions of the traditional laboratory experience, this shortcoming is a significant pedagogical bottleneck. Recent research has focused on creating Collaborative Online Laboratories (COL) which attempt to address this shortcoming by focusing on the group awareness aspect of the laboratory learning experience. This paper discusses how group awareness can serve as a key component in replicating the collaborative aspect of learning in local laboratories. We discuss strategies for describing group awareness and how these strategies are associated both with a tutor's pedagogical objectives and in the management of the group of collaborating students. We describe an experimental system that we have developed that uses Semantic Web technologies to define a knowledge-driven system that allows researchers to describe and execute a variety of collaborative strategies for online laboratories.**

***Index Terms*—Ontology-driven Applications, Adaptive Systems, Remote Laboratories, Computer Supported Collaborative Learning, Web Based Instruction, Ontologies, OWL, SWRL, Rule-Based Systems, Knowledge-Based Systems**

## I. INTRODUCTION

THE field of Online Engineering emerged in the early 2000s from research carried out at the Massachusetts Institute of Technology [1]. Using the Internet and web-based technologies, the goal of online learning is to provide a laboratory learning experience to students who are not physically present in a laboratory. These online laboratories allow students in the various parts of the world to perform engineering laboratories online and use Distance Learning techniques to produce the pedagogical equivalent of *in situ* laboratory sessions [1], [2], [4], [13], [16]. This field grew out of early work that aimed for accurate online reproduction of workbench activities during local laboratory sessions [2], [14], [15].

Current Online Laboratories differ from traditional laboratories in that they typically lack the ability to support collaboration among students [3]. When developing current online systems, researchers are primarily interested in the mechanics of making a laboratory available online, and in the integration of the laboratory with local information systems, especially Learning Management Systems. While these issues are important, the inability to support multiple simultaneous users results in systems that lack a key component of the traditional laboratory learning experience. Collaboration among students is a cornerstone of the local laboratories learning experience as it lets students exchange skills, results, and knowledge, to form groups, and to emulate other group members [5]. Recent research has focused on how to scenarized these interactions in a learners group [8], [9]. Co-construction of knowledge is also one of the basic goals of collaborative learning. These various dimensions of collaboration are important in Engineering Education, particularly in laboratory settings, as they provide the perspective of shaping teaching scenarios that are close to real-world distributed engineering team work [6]. By learning together, students also learn to work in a distributed group of workers, which is otherwise difficult to learn during lectures. Working at distance is also likely to be an important facet of their future life as engineers [7].

To address this limitation, we have developed a collaborative online learning framework with integrated group awareness support [10]. In this system, students connected to an online session are notified not only of the effects of their intended action, but also notified of the possible interactions between this action and the actions of other users. Each online student is assigned a unique visual indicator (usually a color) for the duration of a session and this indicator is used to show the author of each action. When a student indicates that they intend to use a widget, the widget is modified to display the visual indicator assigned to the student. Every connected user is thus aware of the author of every action, and of its consequence. A scenario of this type is illustrated at figure 1, and in an online demonstration video[1].

In such a system, multiple simultaneous users attempting to manipulate the same resource can lead to *widget wars*, which can negatively affect collaboration among learners. In general, a supervisor is present to monitor intendend actions and mediate as needed. To provide assistance to the tutor in the management of the group of connected students, we have developed an ontology-based intelligent system to encode and execute collaboration policies. These policies can be used to adapt the rule governing collaboration among students according to the context of the learning environment and the pedagogical goals of the tutor.

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[1] http://diom.telecom-st-etienne.fr/satin/einst/einst_demo.avi

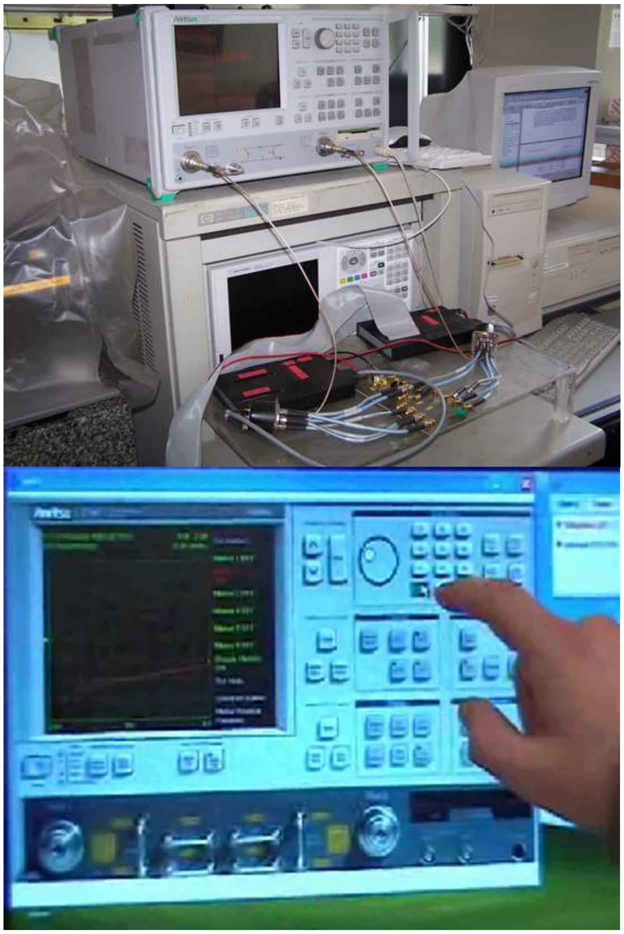

Fig. 1. Real laboratory (top) and associated software (bottom). The equipment is a Vector Network Analyzer. It is used to measure parameters of an electronical network to determine its signal transmission and reflection capacities.

Using semantic technologies to assist education activities is a relatively recent development [11]. Our approach makes use of these technologies to manage collaboration among learners. We provide a domain ontology for collaborative online learning, and present a rule-based system for a tutor to express their strategies in managing these collaborations sessions. We describe a set of example policies and present the rules used to encode those policies. We outline the architecture and an implementation of this semantic system, and describe a user evaluation.

This paper is organized as follows. Section 2 outlines the requirements for the modeling of a collaborative online laboratory. Section 3 and describes the OWL ontology used to model the domain of collaborative online learning. Section 4 shows how it is possible to build strategies for collaboration using this ontology by providing examples of common collaborative policies used in online laboratories. The architecture and implementation of the software system developed to realize these strategies are described in Section 5. Finally, we describe an evaluation showing how teachers and students reacted to this new collaborative learning experience.

## II. Requirements of a Collaborative Online Laboratory

### A. Use Case Scenario

Bob and Alice have participated in a large number of laboratories together during the first two of their 3-year Masters curriculum at the University of Saint-Etienne in France. In their final year, Alice and Bob have chosen a distance learning curriculum which allows them to take 9-month rather than the traditional 6-month internships. Alice is working in a company in London, and Bob, who is fond of Japanese culture, has an internship position in the University of Tokyo. Once a week, they perform distance learning sessions. During these sessions, among other learning activities, they participate in a collaborative online laboratory. They participate in this laboratory under the guidance of Mr. Smith, who is connected at the same time. This laboratory sessions concern signal reflection and transmission in telecommunications and requires the use of a network vector analyzer. In addition to the subject-specific goal of the laboratory activity, Mr. Smith views the teaching of collaboration between Bob and Alice as an important part of the learning experience.

### B. User interactions in Collaborative Online Laboratories

Anticipating the sequence of interactions between users during a session is difficult. The goals of a particular session and thus the interaction sequences may vary depending on the pedagogical goals of the instructor. The goals may also vary due to the individual circumstances of a session. For example, Mr. Smith may decide that Bob, who arrived late to an online session, should have more time than Alice during the session to allow him to catch up with Alice, who arrived at the beginning of the session. Or instead the tutor may want to favor Alice, who was on time. Alternatively, the tutor may decide to give more time to Alice, because she is less confident than Bob about the topic being covered in the session.

Whatever the scenario, the collaborative policies adopted for a session can vary considerably. The range of possible policies is numerous and each policy can potentially be modified to target the goals of an individual session. For these reasons, it is generally not practical to build a moderation unit that can anticipate all possible collaborative policies in advance. Instead, developing a library of policies that covers a range of possible scenarios offers a more practical solution.

Using Semantic Web technologies, we have developed such a policy library. Using the Ontology Web Language (OWL [12]) and the associated Semantic Web Rule Language (SWRL[2]) we have developed a knowledge-based system to describe and operationalize policies in a collaborative online laboratory. The system uses OWL to describe a domain ontology containing the core entities a typical collaborative online environment. It then uses SWRL to encode individual collaborative policies in terms of these domain entities. An individual policy thus corresponds to a set of SWRL rules; a particular policy may be selected by activating the rule set describing that policy.

[2]Semantic Web Rule Language, http://www.w3.org/Submission/SWRL/

## III. A Domain Ontology for Collaborative Online Laboratories

We devloped a domain ontology to describe all core concepts and entities that occur in a collaborative online laboratory. Fig. 2 contains a simplified representation of this ontology.

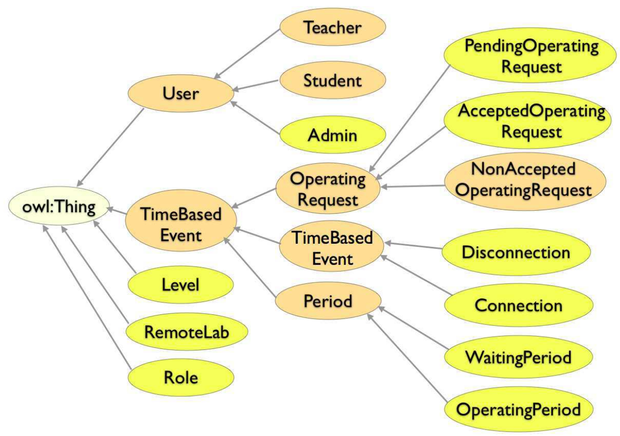


Fig. 2. A simplified view of the ontology of collaborative online laboratory events (light background indicates primitive classes, darker background indicates defined classes).

The ontology focuses on three basic areas:

1) The *role* of the user in an online session. Session participants include learners, teachers and administrators. Policies are generally focused on learners, with the ability to formulate policies typically being restricted to teachers and administrators. The ontology describes these various types of session participants. Each of these participant types are associated with different capabilities.
2) The experience *level* of the user. Various levels of experiences can be assigned to a user, such as, for example, beginner, intermediate, advanced, and expert. For instance, if Alice is familiar with the device she may be assigned an intermediate role, while Bob, who is not, is assigned the role of beginner. These experience levels can be used to constrain the activities a user can perform in a session and to formulate policies based on a user's experience level.
3) The role of *time-based elements*. Time is a central dimension in online laboratories. Policies are generally expressed in terms of the duration, timing, and sequence of events in an online session. The ontology describes the various temporal properties of the entities involved in a session, such as, the connection time of a user, the amount of time a user has waited or has been an operator, and so on.

The ontology was developed on OWL[3]. Simplicity was a major goal when designing this ontology since this approach generally favours reusability, evolution, and sustainability of the ontology [17]. An additional advantage is that it is easier to author and maintain policy rules against a simple ontology.

[3]This ontology can be downloaded from http://dev.telecom-st-etienne.fr/satin/rlab/collaborativev4.swrl.owl.

## IV. Rule-based policies for collaborative learning

### A. Basic collaborative policies

We can now use this ontology to develop collaborative learning policies. For example, we can describe policies to encode the collaborative learning experiences that the aforementioned Mr. Smith wants to provide to both Bob and Alice. Each policy will, for example, encode access conditions for the operator in a session. Individual policies must also anticipate that collaborative sessions evolve over time and consider the state or collaborative context at a particular time in a session. A policy effectively encodes permissible actions within each collaborative context. In other words, users are able to perform commands in a group only if the collaborative context satisfies a given policy.

In our system, we described these collaborative policies using sets of declarative rules encoded using SWRL[4]. SWRL has a number of attractive properties that make it particularly suitable for this task. It is a declarative language based on OWL and it semantics are built on the same description logic foundation that underlies OWL. It allows users to write rules directly in terms of concepts in an OWL ontology. SWRL rules are stored in the associated OWL ontology and effectively form part of it.

For example, let us build an example collaborative policy rule, which can be expressed in natural language as:

> *Policy 1* : If a user has an administrative role and a pending request for being an operator, then make this user the new operator.

Under this collaborative policy, when Mr. Smith requests to be the operator he becomes the operator even if other users are connected to the system.

The next step in building a collaborative policy is to take the natural language description of an individual policy and then express it as a SWRL rule. This rule can be written in SWRL as follows:

$$\begin{cases} Def\_hasOperator : RemoteLab(?r) \ \wedge \ User(?x) \ \wedge \\ hasRole(?x, Administrate) \ \wedge \\ hasPendingOperatingRequest(?x, ?r) \\ \Rightarrow \ hasNextOperator(?r, ?x) \end{cases} \tag{1}$$

This rule can also be expressed as two rules, with one rule for user qualification, and one rule for asserted the next operator.

[4]An introduction to the SWRL language can be found at: http://protege.cim3.net/cgi-bin/wiki.pl?SWRLLanguageFAQ.

$$\begin{cases} Def\_isAdmin : User(?x) \ \wedge \ hasRole(?x, Administrate) \\ \Rightarrow \ Admin(?x) \\ \\ Def\_hasOperator : \ RemoteLab(?r) \ \wedge \ Admin(?x) \\ \wedge \ hasPendingOperatingRequest(?x, ?r) \\ \Rightarrow \ hasNextOperator(?r, ?x) \end{cases} \tag{2}$$

It is worth noting, that separating the rules in this way also favors reusability because the results of the individual more granular rules can be used by other rules.[5].

## B. More complex collaborative policies

More elaborate policies than the one described above are typically required. An example of a more complex policy could be the following:

> *Policy 2* : Give operator status to learners upon request only if they have less accumulated operating time than the current user. This restriction does not apply to teachers and administrators, who are granted preemptive access.

Again, this policy can be expressed as a set of SWRL rules:

$$\begin{cases} Def\_hasAdminOperator : RemoteLab(?r) \ \wedge \\ Admin(?x) \ \wedge \ hasPendingOperatingRequest(?x, ?r) \\ \ \Rightarrow \ hasNextOperator(?r, ?x) \\ \\ Def\_hasTeacherOperator : RemoteLab(?r) \\ \wedge \ Teacher(?x) \ \wedge \ hasPendingOperatingRequest(?x, ?r) \\ \ \Rightarrow \ hasNextOperator(?r, ?x) \\ \\ Def\_hasStudentOperator : RemoteLab(?r) \\ \wedge \ hasOperator(?r, ?s1) \ \wedge \ Student(?s2) \\ \wedge \ hasPendingOperatingRequest(?s2, ?r) \\ \wedge \ hasOperatingPeriod(?s1, ?op1) \\ \wedge \ hasOperatingPeriod(?s2, ?op2) \\ \wedge \ hasDuration(?op1, ?d1) \ \wedge \ hasDuration(?op2, ?d2) \\ \wedge \ swrlb : lessThan(?d2, ?d1) \\ \Rightarrow \ hasNextOperator(?r, ?s2) \end{cases} \tag{3}$$

Other possible collaborative policies include:

- When Bob requests the device control, he is granted the operator status if Bob has less operating time than Alice.
- When Bob requests the device control, he is granted the operator status if it is the first time that he has requested it.
- When Bob requests the device control, he is granted the operator status if he was connected before Alice.
- When Bob requests the device control, it is refused to him if he had more than 5 disconnections in the current session.
- When Bob requests the device control, he is granted the operator status only if he has entered the session more than 10 minutes ago.
- The users are granted a preemptive and dedicated access of 15 minutes. Within those 15 minutes they cannot be preempted by other users (except by administrators and teachers), that also means they cannot preempt other users when it is not their time slot.

Many more policy rules than those presented here are possible and these rules can be combined and reused in many ways to achieve a tutor's goals. Even though our underlying domain ontology is relatively simple, considerable expressivity is afforded with the use of SWRL rules. As can be seen, time plays an important role in most policy rules. Our policy rules make extensive use of a SWRL temporal library [6].

# V. Implementation of the KBS

## A. System Architecture

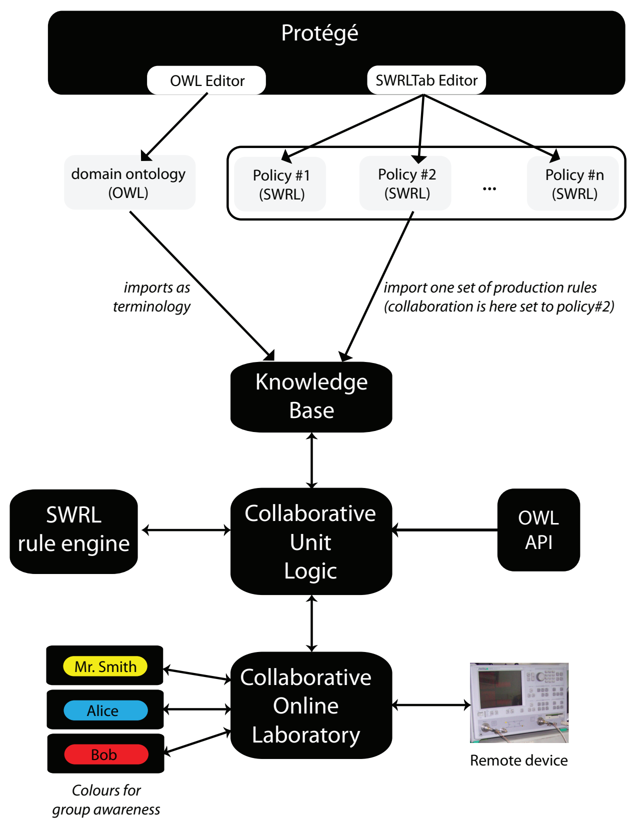


Fig. 3. Implementation of the collaborative process unit.

The collaborative logic and knowledge base are implemented by a Collaborative Unit Logic module (see Fig. 3). This module provides:

- Connections between a collaborative online laboratory and collaborative policies

[5]These rules all other rule sets described in this paper are available at: http://dev.telecom-st-etienne.fr/satin/rlab/policies/rules.zip.

[6]http://protege.cim3.net/cgi-bin/wiki.pl?SWRLTemporalBuiltIns

- All the knowledge related to collaboration and the current state of a session
- Updates knowledge upon new actions over the online laboratory
- Decides, according to the collaborative policy in place, whether or not a user requesting the operator status is granted it or not.

The system implementation relies on widely available, open source Semantic Web software and APIs. The domain ontology was developed using Protégé-OWL and the SWRL policy rules were developed and executed using its SWRLTab plugin [18].

### B. Switching collaborative policies in an online session

Clearly, all sessions within an online laboratory cannot use the same collaborative policy. Even within a single session, the tutor may want to change the policies. For these reasons, we introduce an Adaptive Module, which is responsible for switching from one rules set to another. At the application level, this process involves dynamically switching policy rule sets. This switching process must maintain the current system state.

A possible scenario is as follows: Mr. Smith sets the collaborative policy to the administrator policy so that he can prepare the session for Bob and Alice. Bob and Alice can join the session and see Mr. Smith's actions but they are not allowed to perform any actions themselves. Afterwards, as Mr. Smith wants both Bob and Alice to test the COL, he sets the collaborative policy to favor late comers. The system discards the previous collaborative policy rule set and loads the set representing the new policy. Later, to avoid too much inequality in the access during the session, Mr. Smith sets the collaborative policy to favor users with less operating time. Again, the system has to seamlessly switch from one rule set to another. It should be noted that this approach to implementing collaborative policies is not specific to online laboratories, and thus could be used by other knowledge-based systems that require similar policy mechanisms.

OWL's monotonic inference mechanism must be considered when switching rule sets. Because SWRL rules are logically part of an OWL ontology, retracting one set of rule and asserting another can introduce nonmonotonicity. Designers of adaptive systems that use OWL need to deal with this issue. A possible solution is to discard all current session knowledge when policies are switches, but this approach is clearly unsatisfactory. Ideally, the adaption process should preserve the original context when dynamically loading new rules that encode different policies. A solution that we have adopted is to explicitly identify assertions made by policy rules and to associate a temporal scope or dimension with them to identify their period of validity. Any further assertions made using these assertions must be similarly scoped. When a new policy is activated, these assertions and any further assertions made using them are no longer valid. This solution ensures that no inconsistencies are introduced by rule set switching but it is not a general solution for all adaptive systems. Developers of such systems may need to develop custom solutions for their domain, though the temporal scoping mechanism outlined here is quite robust for this specific system.

## VI. Evaluation

To evaluate user satisfaction with the system, twelve three-hour sessions were arranged. Each session involved 45 students, divided into groups of four (with one oversized group of 5 students). Students in each group were connected to one remote workbench device using a single touch screen. Users remotely handled the workbench while facing questions on the purpose for their hands-on session. The logging system shows that an average of 95 commands were relayed per hour per group of students.

One of the main objectives of online laboratories is to offer a learning experience as close as possible to reality. In particular, the device's HCI is expected to be an accurate facsimile of the physical device's interface. Frequently, learning to use the HCI of a specific piece of equipment is a pedagogical objective itself. In general, HCI quality tend to strongly affect user perception of the overall quality of the collaborative online laboratory experience. Hence, the survey also evaluated user satisfaction with the online device's HCI in addition to evaluating users' overall perception of the system.

The survey questionnaire was dividen into two sections:

- To evaluate the HCI, we generated a user interface evaluation questionnaire using commonly available web software [19]. Three common evaluations heuristics were used in the generation this questionnaire: Nielsen's Attributes of Usability[7], Lewis' works on IBM Computer Usability Satisfaction Questionnaires[8], and Chin's Questionnaire for User Interface Satisfaction[9].
- The second part of the questionnaire was dedicated to the learning experience itself.

The list of survey questions is accessible online [20].

### A. Survey Results

In general, participants thought that a collaborative online laboratory was a very good idea (82%). In response to the question "In your opinion, is it important to collaborate with other people?", more than half (58.82%) thought it was useful to help one another, 32.35% enjoyed comparing their experimental results with other people, and the remaining (8.82%) used it to speak about student parties they had (sic!). They also noted (92.60%) that using a collaborative online laboratory instead of a local laboratory helped them significantly when writing reports, particularly when reproducing result graph. Each of the three HCI evaluation heuristic give approximately the same result for user

[7]http://hcibib.org/perlman/question.cgi?form=NAU
[8]http://hcibib.org/perlman/question.cgi?form=CSUQ
[9]http://hcibib.org/perlman/question.cgi?form=CSUQ

satisfaction for device usability: 62.04% for questionnaire based on Nielsen's work, 59.14 for the one based on Lewis's, and 57.50% for questionnaire from Chin's works (greatest difference is 4.54%). 55.56% of participants assessed the graphical user interface to be very close to the real interface of the remote device, and 40.47% noticed it exhibited only a few differences. The overall performances of the platform were judged satisfactorily by 77.78% of users, even by those using slow laptops (with Intel Celeron processors and 256 Mb of RAM). It is interesting to note that 62.96% of students intentionally attempted actions that were not forecasted by the hands-on session questions, driven primarily by curiosity.

### *B. Informal results*

As mentioned, the teachers were in general satisfied with the system. They stressed three main points:

- The platform allowed them to satisfactorily perform an online laboratory. For most of the teachers, this was the first time that they has participated in such a laboratory. Most saw it as a positive pedagogical experience that contributed to their knowledge of distance learning.
- Teachers tend to put high importance on group awareness and appreciated that the platform allowed them to clearly see which students are more active than others. This requirement is naturally performed in local laboratories where teachers can easily identify weak or strong students. Since distance can introduce a significant decrease of awareness of other persons, group awareness support can be key in compensating for this deficit. Teachers, however, stressed that they may also have to develop new group awareness skills when managing online laboratories.
- Many-to-many online laboratories were also recognized as a way to encourage students to exchange results and support peer assistance in addition to allowing teachers to manage more students than a point-to-point online laboratory.

## VII. CONCLUSION

Our solution supports the development of collaborative policies that reflect the pedagogy that a tutor wishes to promote in collaborative online learning sessions. These collaborative policies are described using SWRL rule sets, which are written on top of an OWL domain ontology that describes the core entities in collaborative online laboratories. These rules encode policies allow the system to determine per user access control policies for devices being used in a session. These access policies reflect the pedagogical goals of a tutor. We have described an implementation of the system and outlined an evaluation. While the ontology and associated policy rule sets is specific to the collaborative online learning domain, the architecture and approach may be generalized to support other adaptive systems for computer-supported collaborative applications. Future work consists in trace mining of events during an online session to measure the quality of collaboration during the session. This mining can be used to identify possible leaders, for example, or to identify weak students who may require more assistance. The underlying challenge is to enhance the learning experience of users in collaborative online learning laboratories to meet the goals of both tutors and students.

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